

THE CARBURIZATION OF STEELS OF
"KRUPP" ANALYSIS
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THESIS

THE CARBURIZATION OF STEELS OF "KRUPP" ANALYSIS

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SYNOPSIS

Samples of four lots of steel containing between 1.75 and 3.79% nickel and between 0.73 and 1.72% chromium were carburized to obtain information on the factors affecting rates and depths of carbon penetration. A review of previous work on carburization and diffusion of carbon is presented, and the relative importance of factors affecting rate of carburization is discussed. It was found that initial grain size had a marked effect on rate of carburization of a steel, and that the variation in alloy content among the different lots of steel had a slight effect on respective rates of carburization.

INTRODUCTION

Few processes have received the attention of metallurgists over a longer period of time than that of carburization of iron and steel. The many variables which affect the process, as well as the differing objectives which have determined the procedures of the respective investigators, have prevented a complete understanding of the laws governing rates and depths of carburization.

It would be out of the question to do justice to, or even to tabulate, in a single paper, the many contributions to our knowledge of this most interesting subject. The review of the subject which precedes the description of the experimental work, therefore, will be restricted to an analysis of factors affecting rates and depths of carburization. It seems well worth while to direct attention to the importance of an understanding of the laws governing rates of diffusion in solid metals for this purpose, as well as to the factors peculiar to reactions in the gaseous medium, which force us to modify our concept of diffusion as a measure of rate of carburization.

THE FUTURE

Few more than a few years ago, the question of the future of the world was a longer period of time than it is now. The many various sides of the question, as well as the different objectives which have been set, the procedure of the respective investigators, have presented a complete misunderstanding of the future governing the world and the future of civilization.

It would be well to ask the question as to whether, or even to tabulate, in a similar manner, the various contributions to our knowledge of this most interesting subject. The review of the subject which precedes the publication of the "Experimental World," therefore, will be restricted to an analysis of factors affecting rates and degree of civilization. It seems well worth while to direct attention to the importance of an understanding of the laws governing rates of diffusion in solid bodies for it is, in fact, as well as to the factors peculiar to reactions in the various media, which force us to modify our concept of diffusion as a measure of rate of civilization.

THE PROCESS OF CARBURIZATION

The surface of a steel specimen is carburized by heating in the presence of a carburizing agent. The essential conditions for carburizing are: that the steel be heated to the austenitic range; that the initial carbon content of the steel be below the limit of solubility at the carburizing temperature; that the carburizing agent react with the iron in such a manner as to give up carbon to the latter.

In carburizing, then, there is a gaseous system which supplies a compound capable of carburizing steel. (The discussion of carburizing with liquids is omitted). There is also a solid system in which the carbon atoms /29/ (or the Fe_3C molecules /21/) diffuses away from the surface, because of the concentration gradient of carbon. At the boundary between the two systems, which may be referred to as the interface, the carburizing gas gives up carbon to the iron, as has been stated.

EQUILIBRIUM

Strictly speaking, equilibrium does not occur in the carburizing process, and every step should be analyzed in terms of rates of reaction. The gaseous system at a distance from the interface is practically in equilibrium, and if carbon is available, as in pack-carburizing, CO_2 will be reduced to CO until the pressures of these two gases are practically at equilibrium for the temperature existing. The solid system is likewise practically at equilibrium at a distance from the interface.

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the latter.

tion, as has been pointed out. In order to be able to determine the concentration of carbon in the boundary between the two systems, which may be referred to as the interface, the carburizing gas gives up carbon to the carbon. At the boundary, because of the concentration gradient of away from the surface, the carbon atoms (C) for the Fe-C molecules (Fe) diffuse into the solid system in (Fe) atoms. There is also a solid system in a compound capable of carburizing steel. (The discussion of carburizing in carburizing steel, there is a gaseous system which supplies

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from the interface. The solid system is likewise practically at equilibrium at a distance λ from the interface. Gases are practically at equilibrium for the temperature existing. During, CO_2 will be reduced to 00 until the pressure of these two gases is practically at equilibrium, and if carbon is available, as in rock-carbonation. The gaseous system at a distance from the interface is practically at equilibrium, and every state should be analyzed in terms of rates of reaction. Strictly speaking, equilibrium does not occur in the surrounding

TEMPERATURE AND ITS EFFECT ON RATE OF CARBURIZATION

The carburizing temperature affects the rate of carburization in various ways.

A high temperature increases rate of diffusion in the solid metal by its effect on the diffusion coefficient (equation 4); and affects the rate of reaction of carbon and iron at the interface. A high temperature also increases the concentration of carburizing gas in such processes as that of pack-carburizing.

The carbon content of the metal at the interface is less than the limiting solubility of the carbon in the metal, which depends on the temperature, as reference to the equilibrium diagram of the iron-carbon system will show. There is evidence /6/ that this solubility limit is approached quite closely in practice, but is in general not reached, by the metal at the interface.

From these considerations it appears that the relation between temperature and rate of carburization is a complex one, and data on the relation of these two variables appearing in the literature /6//26/, are most useful for predicting results of carburization. This type of information is less useful for analysis of variations in rates of carburization, especially in the case of pack-carburizing, because of the difficulty of making accurate corrections for temperature variations.

CARBURIZING MEDIUM AND ITS EFFECT ON RATE OF CARBURIZATION.

Houdremont /6/ reports that a powdered mixture of charcoal 60% by weight and 40% barium carbonate produces a deeper case at moderate carburizing temperatures than illuminating gas or a selected mixture of organic carburizing agents. The same work gives data on other

THE EFFECT OF TEMPERATURE ON THE RATE OF CORROSION

The effect of temperature on the rate of corrosion is a well-known fact.

It is well known that the rate of corrosion increases with increasing temperature.

A study of the effect of temperature on the rate of corrosion of iron in a 10% solution of sodium chloride has been made. The results show that the rate of corrosion increases with increasing temperature. The rate of corrosion is also affected by the concentration of the solution. The rate of corrosion is highest in a 10% solution of sodium chloride and lowest in a 1% solution of sodium chloride.

The results of the study show that the rate of corrosion of iron in a 10% solution of sodium chloride is highest at 40°C and lowest at 10°C. The rate of corrosion is also affected by the concentration of the solution. The rate of corrosion is highest in a 10% solution of sodium chloride and lowest in a 1% solution of sodium chloride. The results of the study show that the rate of corrosion of iron in a 10% solution of sodium chloride is highest at 40°C and lowest at 10°C.

From the results of the study it is concluded that the rate of corrosion of iron in a 10% solution of sodium chloride is highest at 40°C and lowest at 10°C. The rate of corrosion is also affected by the concentration of the solution. The rate of corrosion is highest in a 10% solution of sodium chloride and lowest in a 1% solution of sodium chloride.

This type of information is very useful for the study of corrosion. It is also useful for the study of the rate of corrosion of iron in a 10% solution of sodium chloride. The results of the study show that the rate of corrosion of iron in a 10% solution of sodium chloride is highest at 40°C and lowest at 10°C.

CONCLUSIONS

The results of the study show that the rate of corrosion of iron in a 10% solution of sodium chloride is highest at 40°C and lowest at 10°C. The rate of corrosion is also affected by the concentration of the solution. The rate of corrosion is highest in a 10% solution of sodium chloride and lowest in a 1% solution of sodium chloride. The results of the study show that the rate of corrosion of iron in a 10% solution of sodium chloride is highest at 40°C and lowest at 10°C.

carburizing agents which have even lower carburizing rates. For long carburizing times and temperatures above 950°C . the differences in the rates of carburization obtained under these different conditions become much less /6/, as the carbon concentration at the interface approaches the limit of solubility.

Bramley //26//27//28//29// reports that rate of carburization is greater with either pyridine, methyl cyanide, or ammonia added to CO than when CO is used alone. In each case increasing the rate of supply of the gas increased the rate of carburization. Temperatures from 800 to 1000°C ., times from 5 to 40 hours, and rates of supply of gas from 7 to 30 liters per hour per sample, were used.

Comparison of this work of Bramley with that of Houdremont and Schrader /13/, shows that Charcoal 60% barium carbonate 40% gives as rapid carburization as pure CO if the rate of supply of CO is low, about 15 liters per hour for the conditions existing in Bramley's experiments.

Recent industrial experience /12/ demonstrates that under favorable conditions a combination of CO and hydrocarbon gas produces a higher rate of carburization than CO alone.

It is known that the rate of carburization using charcoal alone in the pack-carburizing process is relatively low.

On the basis of the above information we may conclude that the rate of carburization as measured by the depth of case is approximately proportional to the pressure of CO present. Langenberger /17/ determined this relation experimentally. However, if other carburizing gases are present as well as CO a rate of carburization higher than that obtained with CO alone is observed under some conditions.

It seems most reasonable to postulate that if more than one

It seems reasonable to assume that if more than one

than the rate of change is observed under some conditions.

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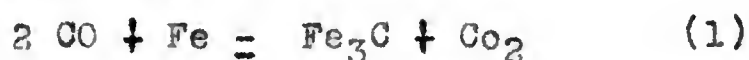
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carburizing gas is present the reactions in the gaseous state proceed more rapidly, so that more carbon can combine with the iron in a given time than would otherwise be the case.

Consider the reactions which take place in carburizing with carbon and an energizer /21/:



If some agent more active than carbon in reducing CO_2 to CO were present, it is reasonable to suppose that carburization would proceed at a more rapid rate.

The carbon content of the surface of the steel cannot be measured very accurately, and figures usually given are the carbon content of a very thin layer removed from the surface. The actual carbon content of the surface approaches the limit of solubility of the steel at the carburizing temperature, and depends on the relative rates of solution of carbon and of diffusion of carbon. If the rate of solution of carbon is relatively low, the carbon content of the surface will likewise be low. For high temperatures and long carburizing times, changing the carburizing medium has relatively little effect on the carbon concentration at the surface and on case depth. /6/

THE CONSTITUTION AND STRUCTURE OF THE STEEL AND ITS EFFECT ON RATE OF CARBURIZATION.

The rate of carburization may be expected to vary with the alloy content of the steel. The limit of solubility of carbon in a steel at a given temperature will vary with the alloy content. Furthermore, it is to be expected that rates of diffusion in different alloys will vary. Houdrement and Schrader /13/ have determined the variation in rate of carburization when up to 6% of an alloying element has been

concentration of carbon in the steel is not too high, the rate of oxidation will be low. If the concentration of carbon is high, the rate of oxidation will be high. The rate of oxidation will also be high if the temperature is high.

Consider the reaction of carbon with oxygen. The reaction is exothermic. The rate of reaction will be high if the concentration of carbon is high and if the temperature is high. The rate of reaction will also be high if the pressure is high.

If the concentration of carbon is high, the rate of oxidation will be high. If the temperature is high, the rate of oxidation will be high. If the pressure is high, the rate of oxidation will be high.

The rate of oxidation of steel is determined by the rate of diffusion of oxygen into the steel. The rate of diffusion of oxygen into the steel is determined by the concentration of oxygen in the atmosphere and the concentration of oxygen in the steel. The rate of diffusion of oxygen into the steel is also determined by the temperature of the steel. The rate of diffusion of oxygen into the steel will be high if the concentration of oxygen in the atmosphere is high, if the concentration of oxygen in the steel is low, and if the temperature of the steel is high. The rate of diffusion of oxygen into the steel will also be high if the pressure of the atmosphere is high.

THE CONCENTRATION AND RATE OF DIFFUSION OF CARBON IN STEEL

The rate of carbonization may be expressed as a function of the concentration of carbon in the steel. The rate of carbonization will be high if the concentration of carbon in the steel is low and if the temperature of the steel is high. The rate of carbonization will also be high if the pressure of the atmosphere is high. The rate of carbonization will be low if the concentration of carbon in the steel is high and if the temperature of the steel is low. The rate of carbonization will also be low if the pressure of the atmosphere is low.

added to steel. A number of common alloying elements were so added, and in most cases the rate of carburization was thereby decreased. Houdremont /6/ has determined that the carbon content within 0.05 m.m. of the surface of several steels when carburized under similar conditions varied as follows: Nickel-chromium steel highest, nickel steel next, carbon steel lowest.

The thickness of the case is dependent on the rate of diffusion of carbon in the metal.

Diffusion of metals in the solid state obeys Fick's law: /22/:

$$D_m = D A \frac{(dc)}{(dx)} dt \quad (3)$$

Where a mass dm of a substance diffuses across an area A in time dt .

dc/dx is the concentration gradient of the diffusing substance, where c is concentration, and x is distance from the interface of the solute metal.

D is the diffusion coefficient, which has been calculated by the Dushman-Langmuir equation as:

$$\log_e D = \log_e \frac{QS^2}{Nh} - \frac{Q}{RT} \quad (4)$$

Where Q is heat of diffusion or solution.

N is Avogadro's number

h is Planck's constant

R is the gas constant

T is the absolute temperature

$$e = 2.718 +$$

S is the interatomic distance.

It has been observed that D varies to some extent as concentration of solute (c) varies, and this is not indicated by equation (4).

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It has been observed that D varies to some extent as concen-

2. is the concentration

$$e = 2.718$$

T is the absolute temperature

R is the gas constant

h is Planck's constant

N is Avogadro's number

Where λ is rate of diffusion or solution.

$$\log_e D = \log_e \frac{h^2}{2\pi^2 N} - \frac{U}{RT}$$

the Darnley-Darnley equation is:

D is the diffusion coefficient, which has been calculated by

the solute metal.

where c is concentration, and x is distance from the surface of

$\frac{dc}{dx}$ is the concentration gradient of the diffusion substance,

dt.

Where a term on the right of diffusion process on axis x in time

$$m = \frac{1}{\sqrt{\pi D t}}$$

Diffusion of metal in the solid state obeys Fick's law (1):

of carbon in the metal.

The thickness of the plate is 0.5 cm. and on a mass of diffusion

highest, nickel steel is 1.5 cm. and 1.5 cm.

under similar conditions the weight of diffusion is 0.1

within 0.02 g. of the surface of several plates were measured

observed. For example, the observed weight of a plate of constant

added, and in most cases the rate of diffusion was directly a-

added to the surface of the plate.

From equation (4) it is apparent that the diffusion coefficient is much larger at higher temperatures, and also that its value depends on the properties of the solute material (in the steel). Equation (4) does not indicate the effect which the presence of one or more alloying elements would have on the diffusion coefficient of carbon in iron.

From consideration of equations (3) and (4) it is observed that rate of carburization, as measured by mass of carbon diffused into the metal, is greater if the carbon gradient (dc/dx), the diffusion coefficient (D), or the absolute temperature (T), is greater.

Furthermore, a greater carbon concentration at the interface will produce a greater depth of case; a large diffusion coefficient will produce a greater depth of case, other conditions being equal.

Mehl /22/ has presented a review of the subject of diffusion in solid metals. It may be said that the theory thus presented has great potential value for analysis of carburization processes. Unfortunately most of the research in carburization yields too little information to permit computation of diffusion coefficients, and thus fails to contribute to knowledge of diffusion. In particular, evaluation of the quantity " $\frac{dm}{dt}$ " equation (3) would be most useful. The total mass of carbon diffused (the area under the depth-concentration curve) gives a means of estimating relative magnitude of mass " m ". (equation 3).

Additional data is needed if the true value of " $\frac{dm}{dt}$ " is to be computed.

No information is available on the effect of the structure of a given alloy on the rate of carburization which may be attained. At the carburizing temperature the steel is austenitic and the effects of previous treatment are not apparent in the structure. However,

From equation (4) it is apparent that the diffusion coefficient D is much larger at higher temperatures, and also that the value of D on the properties of the solute material (the solid). It does not indicate the effect of the nature of the alloying elements would have on the diffusion coefficient of certain elements. From consideration of equation (4) it is observed that rate of carburization, as measured by mass of carbon diffused into the metal, is greater if the diffusion coefficient D is greater. Coefficient (5), or the effective diffusion coefficient D_{eff} , is greater. Furthermore, a greater carbon concentration at the surface of the metal will produce a greater depth of the diffusion front. A constant D_{eff} will produce a greater depth of the diffusion front under other conditions being equal. Mehl (19) has obtained a series of the rate of diffusion in solid metals. It may be said that the theory thus presented is of great practical value for analysis of carburization processes. Unfortunately most of the research in carburization yields too little information to permit determination of diffusion coefficients, and thus fails to contribute to knowledge of diffusion. In particular, evaluation of the quantity $\frac{dQ}{dt}$ (equation (3)) would be most useful. The total mass of carbon diffused, the area under the depth-concentration curve, gives a means of estimating relative magnitude of D_{eff} . (equation 3).

Additional data is needed if the time value of $\frac{dQ}{dt}$ is to be computed.

No information is available on the effect of the structure of a given alloy on the rate of carburization which may be attained. At the carburizing temperatures the steel is austenitic and the effects of previous treatment are not apparent in the structure. However,

there are properties of the steel associated with the McQuaid-Ehn grain size /2//3//20//23/ which are retained after heating and cooling steel through the austenitic range. In spite of the work of Grossman /2//3/ and others the true cause of the inherent grain size of the steel is not definitely known. It is at least possible that the previous treatment of the steel may have some effect on its rate of carburization.

PROPERTIES OF THE MATERIAL UNDER TEST

Two steels of an alloy content approximating that of Krupp armor steels, and two steels of somewhat lower alloy content were selected for test. Analyses of these steels are given in Table I. They were selected from several regular lots offered by commercial concerns, the idea being to conduct the tests on samples representative of good commercial practice.

These steels are characterized by very high strength, good ductility, toughness, and resistance to shock; and are sluggish in response to heat treatment, becoming pearlitic only when annealed slowly. Steels of Krupp analysis are known to be susceptible to temper brittleness under some conditions of heat treatment.

Steel SAE No. 1020 is a plain carbon steel included in the investigation as a control.

The material was furnished by the respective manufacturers in rods approximately 1" in diameter. Steels A and B being hot rolled and steels C, D and E being hot forged. The samples were examined for elongated grains which would indicate too low finishing temperature. None were found.

Table III gives the data on critical points of these steels,

There are specimens of the steel which have been subjected to grain size 100/100/100/100 and others which have been subjected to grain size 100/100/100/100. The grain size of the steel through the austenitic region is 100/100/100/100 and others are 100/100/100/100. The grain size of the steel is not definitely known. It is of the order of 100/100/100/100. The previous treatment of the steel has been the effect of the annealing operation.

ANALYSIS OF THE STEEL

Two steels of an alloy content are examined. The first steel is a plain carbon steel and the second steel is an alloy steel. The analysis of these steels are given in Table I. They were selected from several different lots offered by commercial concerns. The fact being to compare the steel on some of the properties of good commercial steels. These steels are characterized by very high strength, good ductility, toughness, and resistance to shock; and are slightly in response to heat treatment, becoming martensitic only when annealed slowly. Steels of this analysis are known to be susceptible to temper brittleness under some conditions of heat treatment. Steel No. 1020 is a plain carbon steel included in the investigation as a control.

The material was furnished by the respective manufacturers in rods approximately 1" in diameter. Steels A and B being hot rolled and steels C, D and E being hot forged. The samples were examined for elongated grains which would indicate too low finishing temperature. None were found. Table III gives the data on critical points of these steels.

the values given in the literature /21/ for the nominal composition being corrected for variations from this composition by use of factors determined by Reed /18/. In no case did the value of this correction exceed 3°F. The values of carbon content of the eutectoid are also based on work of Reed./18/.

This work of Reed, while not very accurate, is the best that is available for the purpose.

EXPERIMENTAL PROCEDURE

In order to determine the effect of initial structure of the sample on rate of diffusion, samples of each steel were heated to various temperatures, for various times, as indicated in Table II.

Various means were used to protect the specimens from oxidation in the cases of Steels A and B, Steels C and D, and E, were treated in a chromium steel container in a nitrogen atmosphere. A Westinghouse Globar furnace was used, with automatic temperature control, and a separate thermocouple was used to check temperatures as close to the specimens as possible.

Each specimen was centered in a lathe, and turned accurately to a cylinder. In so doing, a layer of metal from 1/16" to 1/8" thick was cut off from the surface, thus disposing of material which might have undergone decarburizing during ^{heat treatment.} A feed of 0.005" per revolution was used on the final cut to give uniform surface

The specimens were then carburized in batches as indicated in Table II, in a mixture of 60% powdered charcoal by weight, and 40% powdered barium carbonate. It should be noted at the temperatures used the samples were initially above the upper critical point (Ac3) and hence austenitic. The original grains were recrystallized.

the values given in the literature for the values of the rate of diffusion being corrected for variations from the values of the rate of diffusion determined by the literature. In no case did the values of the rate of diffusion exceed 50%. The values of oxygen content of the metal were based on weight of loss.

This work of the author is available for the use of the public.

EXPERIMENTAL PROCEDURE

In order to determine the effect of initial concentration of the sample on rate of diffusion, samples of steel were heated to various temperatures, for various times, as indicated in Table I. Various means were used to treat the specimens for oxidation in the cases of Steels A and B, Steels C and D, and E, which were heated in a chromium steel container in a nitrogen atmosphere. A heating house (Globe Furnace) was used, with automatic temperature control, and a separate thermocouple was used to check temperature of the metal to the accuracy of 0.1°C.

Each specimen was heated in a bath, and turned frequently to a cylinder. In so doing, a layer of metal from 1/16" to 1/8" thick was cut off from the surface, thus disposing of material which might have undergone decarburizing during a heat of 1,000°C. or more. The amount of metal removed was determined by weighing the specimen in the final cut to give uniform weight. Table II, in a mixture of 60% powdered charcoal by weight, and 40% powdered barium carbonate. It should be noted that the temperatures used the samples were initially above the upper critical point (A_{cm}) and hence austenitic. The original grains were recrystallized.

Every sample was carburized 12 hours at the temperature indicated in Table II; this time does not include time to raise the specimen to temperature or cool it. The cooling rates varied in a regular manner from 2°F. per minute shortly after the current was turned off to 1°F. per minute at about 300°F.; and from 300°F. to room temperature cooling, Rates were below 1°F. per minute.

After cleaning, the specimens were returned to the lathe and successive layers of metal 0.0070" to 0.0150" thick were removed and the turnings analyzed for carbon content by the combustion method. Careful records were kept of the diameters of the specimens after each operation in order that the location of each sample of metal analyzed might be used in plotting curves of carbon concentration against depth. A sufficient length was left on each specimen so that a sample 1" from the end of the specimen could be removed for microscopic examination. Photomicrographs which appear to be of interest are included in this report.

Conclusions in regard to rates of carburization were based on examination of depth-carbon concentration curves. This technique gives more accurate measure of depth of case than visual examination of microstructures and also reveals the distribution of carbon within the case.

The relative mass of carbon diffused, as given by the tables, may be converted to lb. of carbon per square inch of area per hour by multiplying by 5.9×10^{-13} .

In making up the tables, the area under the depth-carbon concentration curve was measured down to the 0.25% carbon ordinate in the case of Steel A and down to the 0.40% carbon ordinate in the case of Steels B, C, D, and E. These values correspond to the approximate carbon contents of the original samples. The purpose of

this procedure was to omit from the calculations the original carbon contents, and base conclusions on the mass of carbon added in each case.

Furthermore, errors due to minor variations in initial carbon content are thus reduced to negligible proportions. ^{The} ~~Steel~~ initial diffusion rate is higher due to higher carbon gradient. (Equation 3.) The error due to low initial carbon content of steel A is "on the side of safety". No matter what its numerical value, it can not affect the verity of the conclusion to be stated.

this procedure was to call the attention of the
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case.

Furthermore, errors due to other
contentions that had not been previously
discussion was to be made as to the
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RESULTS

Effect of initial structure on rate of carburization.

Table II and figure 11 show that rate of carburization in Steel C is practically independent of initial grain size as produced by annealing. Steel C has a slightly lower alloy content than the usual Krupp analysis of armor steel. Rate of carburization is very slightly increased by long heating just below the critical range, so that the sample is partly spheroidized. (Specimen C 4).

The rate of carburization of Steel D is increased to a marked degree by increasing initial grain size by annealing, as may be noted by reference to Table II and figures 11 and 14. The rate of carburization is also increased by spheroidizing treatment. (Specimen D 4).

The rate of carburization of Steel E is practically independent of initial heat treatment. (Table II figure 11).

The rate of carburization of Steel A, which is a plain carbon steel, is increased somewhat by annealing to increase grain size (Table II and figures 12 and 15). A somewhat greater increase in rate of carburization was obtained by a quenching treatment. (Specimens A 5 and A 6).

In Steel B, which has an alloy content slightly greater than the usual Krupp analysis for armor steel, the effect of initial structure was in part obscured by the variety of heat treatments undertaken. A coarse-grained structure obtained by air cooling (martensitic) permitted a lower rate of carburization than a structure obtained by annealing. (Table II and figures 12 and 16).

The average mass of carbon diffused is computed in each case where a number of samples had received identical treatment, and the

Effect of initial atmosphere on rate of carburization.

Table II and Figure 11 show that rate of carburization in steel is practically independent of initial atmosphere, as indicated by an analysis of variance. Steel 0 has a slightly lower alloy content than the other steels. Rate of carburization is very slightly increased by long heating time before the initial heating, so that the sample is partly carburized. (Section 4.4).

The rate of carburization of steel 0 is increased to a marked degree by increasing initial grain size by annealing; it may be noted by reference to Table II and Figure 11 and 12. The rate of carburization is also increased by austenitizing treatment. (Section 4.4).

The rate of carburization of steel 0 is practically independent of initial heat treatment. (Table II, Figure 11).

The rate of carburization of steel 0, like the other steels, is increased consistently by annealing to increase grain size (Table II and Figure 11 and 12). A somewhat greater increase in rate of carburization was obtained by a quenching treatment. (Steel-0 means A 8 and A 9).

In steel 0, which has an alloy content slightly greater than the usual Krupp analysis for armor steel, the effect of initial structure was in part obscured by the variety of heat treatments undertaken. A comparison of structure obtained by air cooling (cast-structure) permitted a lower rate of carburization than a structure obtained by annealing. (Table II and Figure 12 and 13).

The average mass of carbon diffused is computed in each case where a number of samples had received identical treatment, and the

results tabulated in the last four lines of Table IV.

Effect of alloy content on rate of carburization. (Figures 11 and 12).

In analyzing the effect of alloy content on rate of carburization, it is necessary to make allowance for the effect of initial grain size. If the results for all samples of each steel are considered, as averaged in Table IV, Steel A has the lowest rate of carburization, C and E carburize at the same rate, and Steel D has the highest rate. Steel B was carburized at a lower temperature, and the rate of carburization was low. No definite conclusion can be drawn by comparing this rate with rates of carburization of the other steels. If the carburizing rates of the steels in the fine-grained condition are compared, (Table II), it will be observed that Steel D carburizes at the same rate as steels C and E, Steel A still showing the lowest rate of carburization.

Carbon, chromium, molybdenum, and to a less degree manganese, may be lost from the surface of the specimen in heat treating.

Examinations of the microstructure indicated that the layer of metal removed after heat treating was in each case sufficient to assure that the sample as carburized was homogeneous and the original alloy content unaltered, except in samples A4, B3, B4 and B5. As the layer removed from Sample E1 was comparatively thin, a chromium analysis was made of the outer layer removed after carburization, in addition to the carbon analysis. Chromium content was 0.71% as compared with an original chromium content of 0.75%. From this it was concluded that the original alloy content was not changed sufficiently to affect the results. Specimen A4 was almost completely

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IT WILL BE UNDERSTOOD THAT NO DAMAGE WILL BE DONE

• (S) БПВ

→ and some of the other things that are going to be with the... all

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

-17000 BT End Date 06/07/98 11:00 AM Page 11

-The "C" is used as a form of address, as in "C" or "C's".

and the fact that the only person who was not a member of the "Political Club" was the only person who was not a member of the "Political Club" was the only person who was not a member of the "Political Club".

10-10-1964

the rate of which was also held steady at 100 percent.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040

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U-1000. In 1968, the U.S. Navy was able to recover the wreckage of the ship.

CONFIDENTIAL

.NOTES: Attached to entry number 100

SECRETARY OF DEFENSE

may be used for other purposes.

To install and start detecting a device, you will need to use the following:

-2- of the following cases at each office of the Department:

1. The first step in the process is to identify the problem or issue that needs to be addressed. This involves gathering information and understanding the context of the situation.

01 05 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100 102 104 106 108 110 112 114 116 118 120 122 124 126 128 130 132 134 136 138 140 142 144 146 148 150 152 154 156 158 160 162 164 166 168 170 172 174 176 178 180 182 184 186 188 190 192 194 196 198 200 202 204 206 208 210 212 214 216 218 220 222 224 226 228 230 232 234 236 238 240 242 244 246 248 250 252 254 256 258 260 262 264 266 268 270 272 274 276 278 280 282 284 286 288 290 292 294 296 298 300 302 304 306 308 310 312 314 316 318 320 322 324 326 328 330 332 334 336 338 340 342 344 346 348 350 352 354 356 358 360 362 364 366 368 370 372 374 376 378 380 382 384 386 388 390 392 394 396 398 400 402 404 406 408 410 412 414 416 418 420 422 424 426 428 430 432 434 436 438 440 442 444 446 448 450 452 454 456 458 460 462 464 466 468 470 472 474 476 478 480 482 484 486 488 490 492 494 496 498 500 502 504 506 508 510 512 514 516 518 520 522 524 526 528 530 532 534 536 538 540 542 544 546 548 550 552 554 556 558 560 562 564 566 568 570 572 574 576 578 580 582 584 586 588 590 592 594 596 598 600 602 604 606 608 610 612 614 616 618 620 622 624 626 628 630 632 634 636 638 640 642 644 646 648 650 652 654 656 658 660 662 664 666 668 670 672 674 676 678 680 682 684 686 688 690 692 694 696 698 700 702 704 706 708 710 712 714 716 718 720 722 724 726 728 730 732 734 736 738 740 742 744 746 748 750 752 754 756 758 760 762 764 766 768 770 772 774 776 778 780 782 784 786 788 790 792 794 796 798 800 802 804 806 808 810 812 814 816 818 820 822 824 826 828 830 832 834 836 838 840 842 844 846 848 850 852 854 856 858 860 862 864 866 868 870 872 874 876 878 880 882 884 886 888 890 892 894 896 898 900 902 904 906 908 910 912 914 916 918 920 922 924 926 928 930 932 934 936 938 940 942 944 946 948 950 952 954 956 958 960 962 964 966 968 970 972 974 976 978 980 982 984 986 988 990 992 994 996 998 1000 1002 1004 1006 1008 1010 1012 1014 1016 1018 1020 1022 1024 1026 1028 1030 1032 1034 1036 1038 1040 1042 1044 1046 1048 1050 1052 1054 1056 1058 1060 1062 1064 1066 1068 1070 1072 1074 1076 1078 1080 1082 1084 1086 1088 1090 1092 1094 1096 1098 1100 1102 1104 1106 1108 1110 1112 1114 1116 1118 1120 1122 1124 1126 1128 1130 1132 1134 1136 1138 1140 1142 1144 1146 1148 1150 1152 1154 1156 1158 1160 1162 1164 1166 1168 1170 1172 1174 1176 1178 1180 1182 1184 1186 1188 1190 1192 1194 1196 1198 1200 1202 1204 1206 1208 1210 1212 1214 1216 1218 1220 1222 1224 1226 1228 1230 1232 1234 1236 1238 1240 1242 1244 1246 1248 1250 1252 1254 1256 1258 1260 1262 1264 1266 1268 1270 1272 1274 1276 1278 1280 1282 1284 1286 1288 1290 1292 1294 1296 1298 1300 1302 1304 1306 1308 1310 1312 1314 1316 1318 1320 1322 1324 1326 1328 1330 1332 1334 1336 1338 1340 1342 1344 1346 1348 1350 1352 1354 1356 1358 1360 1362 1364 1366 1368 1370 1372 1374 1376 1378 1380 1382 1384 1386 1388 1390 1392 1394 1396 1398 1400 1402 1404 1406 1408 1410 1412 1414 1416 1418 1420 1422 1424 1426 1428 1430 1432 1434 1436 1438 1440 1442 1444 1446 1448 1450 1452 1454 1456 1458 1460 1462 1464 1466 1468 1470 1472 1474 1476 1478 1480 1482 1484 1486 1488 1490 1492 1494 1496 1498 1500 1502 1504 1506 1508 1510 1512 1514 1516 1518 1520 1522 1524 1526 1528 1530 1532 1534 1536 1538 1540 1542 1544 1546 1548 1550 1552 1554 1556 1558 1560 1562 1564 1566 1568 1570 1572 1574 1576 1578 1580 1582 1584 1586 1588 1590 1592 1594 1596 1598 1600 1602 1604 1606 1608 1610 1612 1614 1616 1618 1620 1622 1624 1626 1628 1630 1632 1634 1636 1638 1640 1642 1644 1646 1648 1650 1652 1654 1656 1658 1660 1662 1664 1666 1668 1670 1672 1674 1676 1678 1680 1682 1684 1686 1688 1690 1692 1694 1696 1698 1700 1702 1704 1706 1708 1710 1712 1714 1716 1718 1720 1722 1724 1726 1728 1730 1732 1734 1736 1738 1740 1742 1744 1746 1748 1750 1752 1754 1756 1758 1760 1762 1764 1766 1768 1770 1772 1774 1776 1778 1780 1782 1784 1786 1788 1790 1792 1794 1796 1798 1800 1802 1804 1806 1808 1810 1812 1814 1816 1818 1820 1822 1824 1826 1828 1830 1832 1834 1836 1838 1840 1842 1844 1846 1848 1850 1852 1854 1856 1858 186

the paper received from the 1990s to the 2000s, and the paper received from the 2000s to the 2010s.

...to be a

Approved for release by NSA on 08-28-2014 pursuant to E.O. 13526

It is noted that the above information was obtained from the records of the FBI, and is not to be used for any other purpose than the one for which it was obtained.

-The portfolio for new income will include debt and equity securities

violation should not be considered a violation of the act.

decarburized before carburizing. (Table II). The rate of carburization was 20% less than in a sample which had received a similar heat treatment and which had been protected from decarburization. This result is consistent with the findings of Bramley /26/.

Notes on microstructure.

The grain size of both the case and the core of Steels A and D after carburizing was influenced by the initial grain size, initially coarse-grained samples showing larger grains after carburizing in both the case and the core. (Figures 3, 4, 7). These steels were carburized less than 200° F. above the upper critical (Ac3) point. The final grain size of Steels C and E carburized more than 200° F. above the Ac3 point was independent of the initial grain size.

The depth of carburization as determined by microscopic examination of the etched specimens at 10x and 100x was consistent with the determinations based on carbon analysis in the cases of Steels A and B, and was inaccurate in the cases of Steels C and D. The observed depth of case is sensitive to minor changes in technique in etching with 4% nitric acid in alcohol.

The determination of grain size by comparing with standard grain size charts and converting grain size number to linear dimension of the grain by computation was found the most satisfactory method, in view of the variation in the microstructures of the different steels. In the spheroidized steels, for example, it would be difficult to devise a grain count method that would describe the appearance of the steel.

Samples of Steels C and D before carburizing were examined under a microscope 2000x. In the fine-grained samples of Steel D the grain boundary constituents (etched dark with the nital) seemed to form networks about the light-colored grains; whereas in the other samples examined the grain boundary constituents were more discontinuous. In spheroidized samples, of course, nothing resembling grain boundary networks were observed.

Samples of plates 6 and 7 before centrifuging were stained in an
 ultraviolet microscope. In the fine-structure (stained with the nitro) seemed to form
 boundary constituents (stained with the nitro) seemed to form
 networks about the light-colored grains; however in the other samples
 examined the grain boundary constituents were not distinguishable. In
 spherulitized samples of course, nothing resembling grain boundary
 networks were observed.

DISCUSSION

Effect of initial structure of steel on rate of carburization

In this work no exceptions were found to the statement that initial grain size affected the final grain size and rate of diffusion of carbon, when the carburizing temperature was less than 200°F. above the upper critical point (Ac3).

Nothing has been said of the austenitic grain size of the steels which were carburized. It is not believed that variations in austenitic grain size or discontinuities in the lattice structure of the metal affect the rate of carburization. Mehl, in commenting on the work of Mooradian and Norton /7/, observed that the diffusion in some binary metallic systems occurs at a rate apparently independent of the presence of grain boundaries, and recently referred to the fact that this applies as well to the iron-carbon system.¹²² It should be said that the experimental evidence rests on a limited number of observations, and there is at least one exception; thorium diffuses in tungsten much more rapidly along the grain boundaries than through the grains /8/.

However, Epstein and Rawdon /14/ observed that abnormal steels carburized at a lower rate than normal steels, the latter of course having a much larger initial grain size. Apparently they did not investigate the effect on rate of carburization of varying the grain size of one lot of steel. Rowland and Upthegrove/5/ recently determined that large initial grain size of steel accelerated the loss of carbon through surface decarburization.

An explanation of the variations in rates of diffusion described above, may be stated as follows:

DISCUSSION

Effect of initial structure of steel on rate of carburization. In this work no exceptions were found to the statement that initial grain size affected the final grain size and rate of diffusion of carbon, when the carburizing temperature was held at 3000°F. Above the lower critical point (A₁).

Nothing has been said of the relationship in size of the steels which were carburized. It is not believed that variations in austenitic grain size or distribution in the ferrite structures of the metal affect the rate of carburization. Most of the work on the work of Robertson and Hoxton (7), observed that the diffusion in some binary metallic systems occurs at a rate which is independent of the presence of grain boundaries, and recently referred to the fact that this is also as well to the iron-carbon system. It should be said that the experimental evidence rests on a limited number of observations, and there is at least one exception; ferritic steels in temper which were rapidly cooled from the grain boundaries than through the grains (8).

However, Robertson and Hoxton (7) observed that abnormal steels carburized at a lower rate than normal steels, the latter of course having a much larger initial grain size. Apparently they did not investigate the effect on rate of carburization of varying the grain size of one lot of steel. Howland and Ustehrova (5) recently determined that large initial grain size of steel accelerated the loss of carbon through surface decarburization.

An explanation of the variations in rates of diffusion described above, may be stated as follows:

Rate of diffusion of carbon in the austenitic grains of the alloy is more rapid than the rate of diffusion in the material at the grain boundaries. These "grain boundary constituents" are so stable that they remain effective as barriers to the diffusion of carbon about 200°F., above the critical point (Ac3).

Of course, if the material is spheroidized, it is reasonable to expect that the "barriers" will be broken up and the resistance to diffusion diminished. A statement of the composition of these "grain boundary constituents" is not absolutely necessary.

McQuaide states /23/ that inherent grain size (as evidenced by the McQuaid-Ehn grain size for instance) depends on the presence of compounds of aluminum, vanadium, etc., at grain boundaries /4/. Davey /9/ believed that carbides, nitrides, and oxides segregated in the dendritic structure of steel impede the diffusion of carbon. It will no doubt occur to the reader that the same constituents (or properties) which influence the McQuaid-Ehn grain size may possibly affect the rate of diffusion of carbon. However, there is only indirect evidence at best to support conclusions in regard to the effect of non-metallic inclusions on the structure of steels.

EFFECT OF VARYING ALLOY CONTENT OF STEEL ON RATE OF CARBURIZATION

The work of Houdremont and Schrader /13/ has been referred to. As a result of this work they listed certain elements which when added to steel in amounts up to 6% accelerated diffusion; others which retarded diffusion; and still others which had little effect on diffusion. The effect of each alloying element on final grain size was also recorded. The writer plotted the case depths against final grain sizes as obtained by Houdremont and Schrader, and observed

Rate of diffusion of carbon in the austenite is not of the
 alloy is more rapid than in the case of diffusion in a pure iron
 the grain boundaries. These boundaries are not continuous, but are
 stable in the sense that they remain effective as barriers to the
 carbon about 2000°C. above the critical point (1000°C.).
 Of course, the rate of diffusion is not uniform, but is faster in the
 exact line of the "barriers" with the grain boundaries and the grain
 diffusion is not of the same order of magnitude as the grain
 "grain boundary" diffusion is not appreciable in a pure iron.
 The grain boundaries are not continuous, but are broken up by
 the grain boundaries (see Fig. 1) and the rate of diffusion is
 common to all grains, and is not appreciable in a pure iron.
 Davey (8) has shown that carbon is not appreciable in a pure iron.
 in the grain boundaries of steel alloys are still slow of carbon.
 It will no doubt occur to the reader that the same considerations (on
 properties) which influence the rate of grain growth may possibly
 affect the rate of diffusion of carbon. However, there is only in-
 direct evidence of this, and no direct evidence in regard to the ef-
 fect of non-metallic inclusions on the structure of steels.

EFFECT OF VARYING ALLOY CONTENT ON RATE OF DIFFUSION

The work of Henderson and Corbridge (9) has been referred to.
 As a result of this work they listed certain elements which were
 added to steel in amounts up to 0.5% accelerated diffusion, others
 which retarded diffusion, and still others which had little effect
 on diffusion. The effect of each alloying element on final grain
 size was also recorded. The writer plotted the grain size against
 final grain size as obtained by Henderson and Corbridge, and observed

that rate of diffusion increased in a fairly regular manner as the grain size of the carburized specimens increased. In most cases it did not seem to matter greatly which alloying element was present. Aluminum and chromium were conspicuous exceptions. Each one decreased the rate of diffusion and increased the grain size. The information available was insufficient to attempt a correlation of rate of diffusion with initial grain size.

In the opinion of the writer, a more complete understanding of the effect of alloying additions on rate of diffusion would result if these additions were studied from the point of view of their effect on the grain size of the steel.

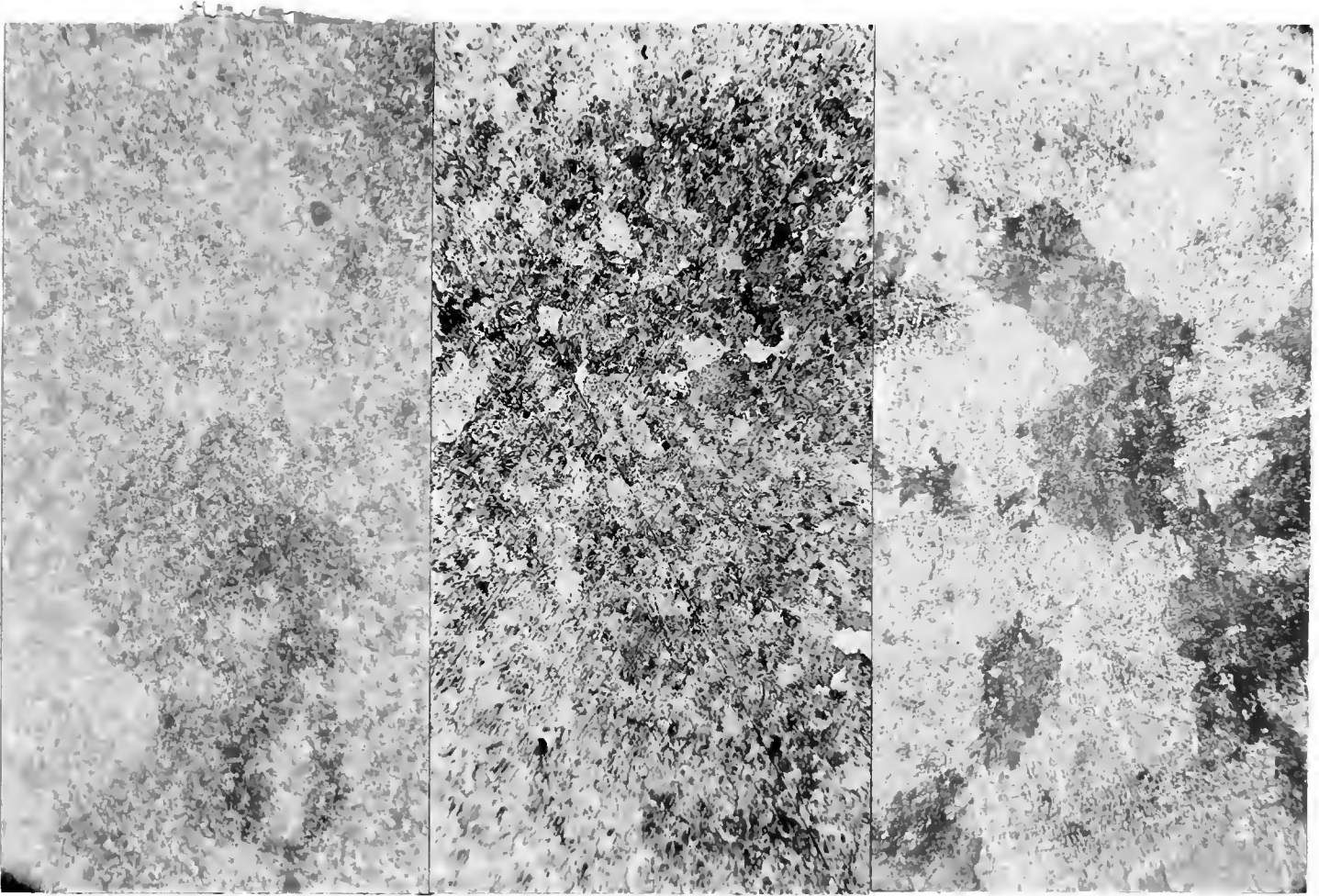
ACKNOWLEDGEMENT

The writer desires to express his appreciation of the cooperation of the Allegheny Steel Company, the Carnegie-Illinois Steel Corporation, the Inspector of Naval Material at Munhall, Penna., the Republic Steel Corporation, and the Midvale Company, in furnishing samples required for test, and performing chemical analyses; and of the personnel of the Metals Research Laboratory and Department of Metallurgy, Carnegie Institute of Technology, for valuable advice and suggestions.

that rate of diffusion increased in a linear fashion with the grain size of the original material. It was found that the rate of diffusion did not seem to matter greatly in the case of the diffusion of aluminum and chromium into steel. The rate of diffusion and increased the rate of diffusion of these elements available for diffusion of steel. In the case of the diffusion of these elements into steel, the effect of the grain size of the steel was not significant. In the case of the diffusion of these elements into steel, the effect of the grain size of the steel was not significant. In the case of the diffusion of these elements into steel, the effect of the grain size of the steel was not significant.

REFERENCES

The writer desires to express his appreciation to the cooperation of the Allegheny Steel Company, the Carnegie-Illinois Steel Corporation, the Inspector of Naval Material at Annapolis, Maryland, the Republic Steel Corporation, and the Bridge Company, in furnishing samples for test, and performing chemical analyses; and of the personnel of the Naval Research Laboratory and Department of Metallurgy, Carnegie Institute of Technology, for valuable advice and suggestions.



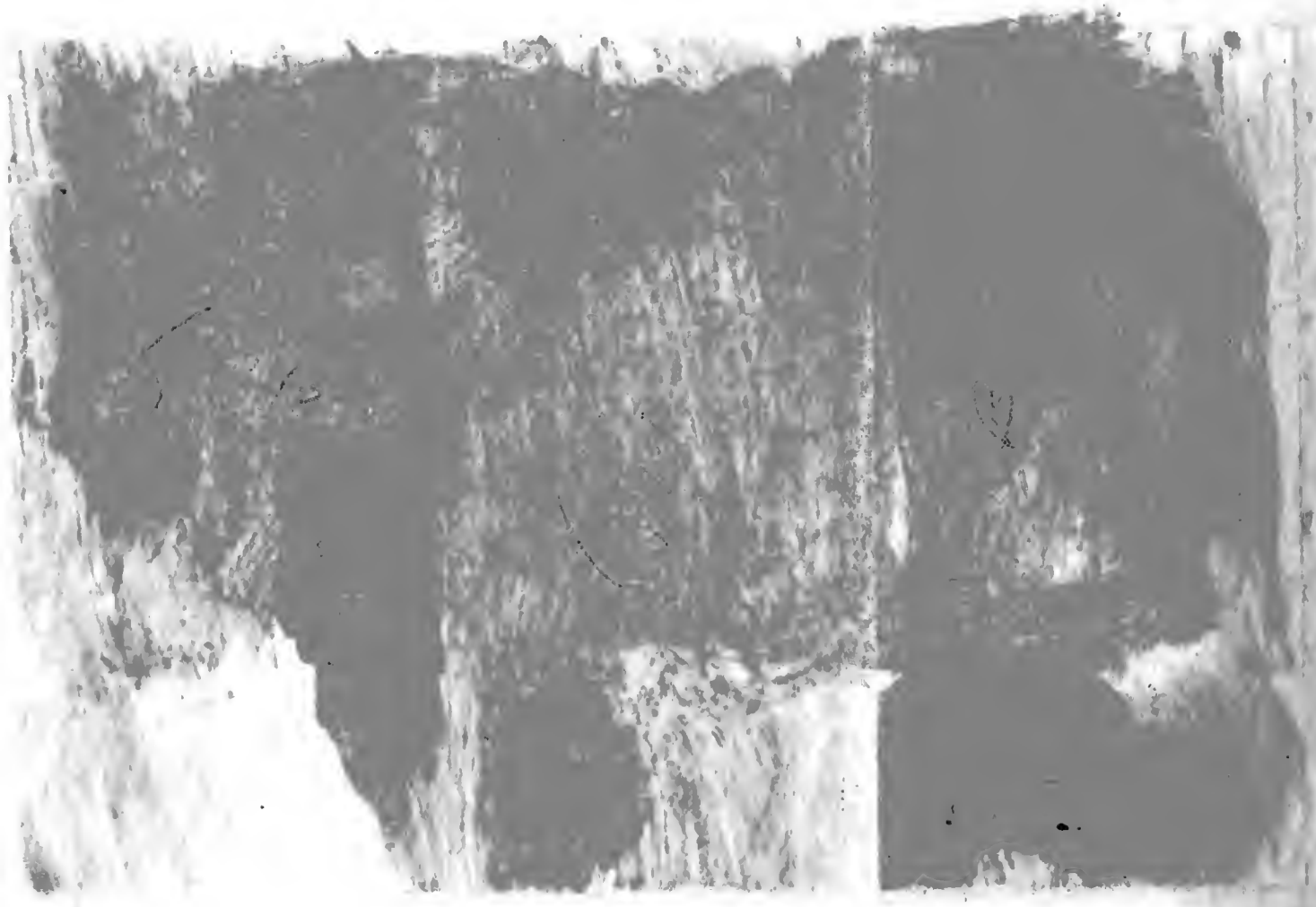
a
Annealed from 1600
Steel C

b
Annealed from 1850

c
Annealed from 2100F

Figure 1..

Magnification 100 X

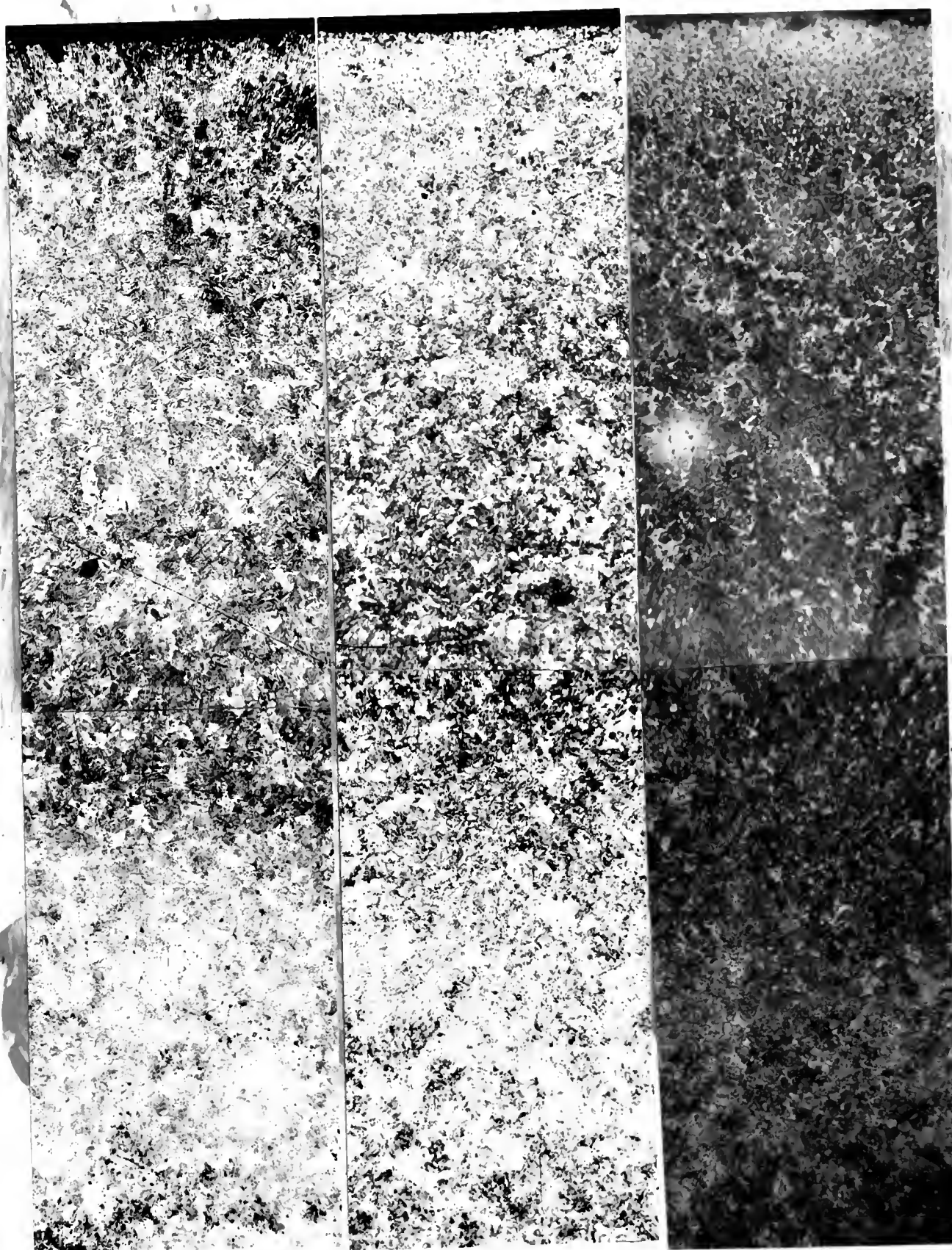


Steel C
Annealed from 1800

Steel C
Annealed from 1800

Steel C

Steel C



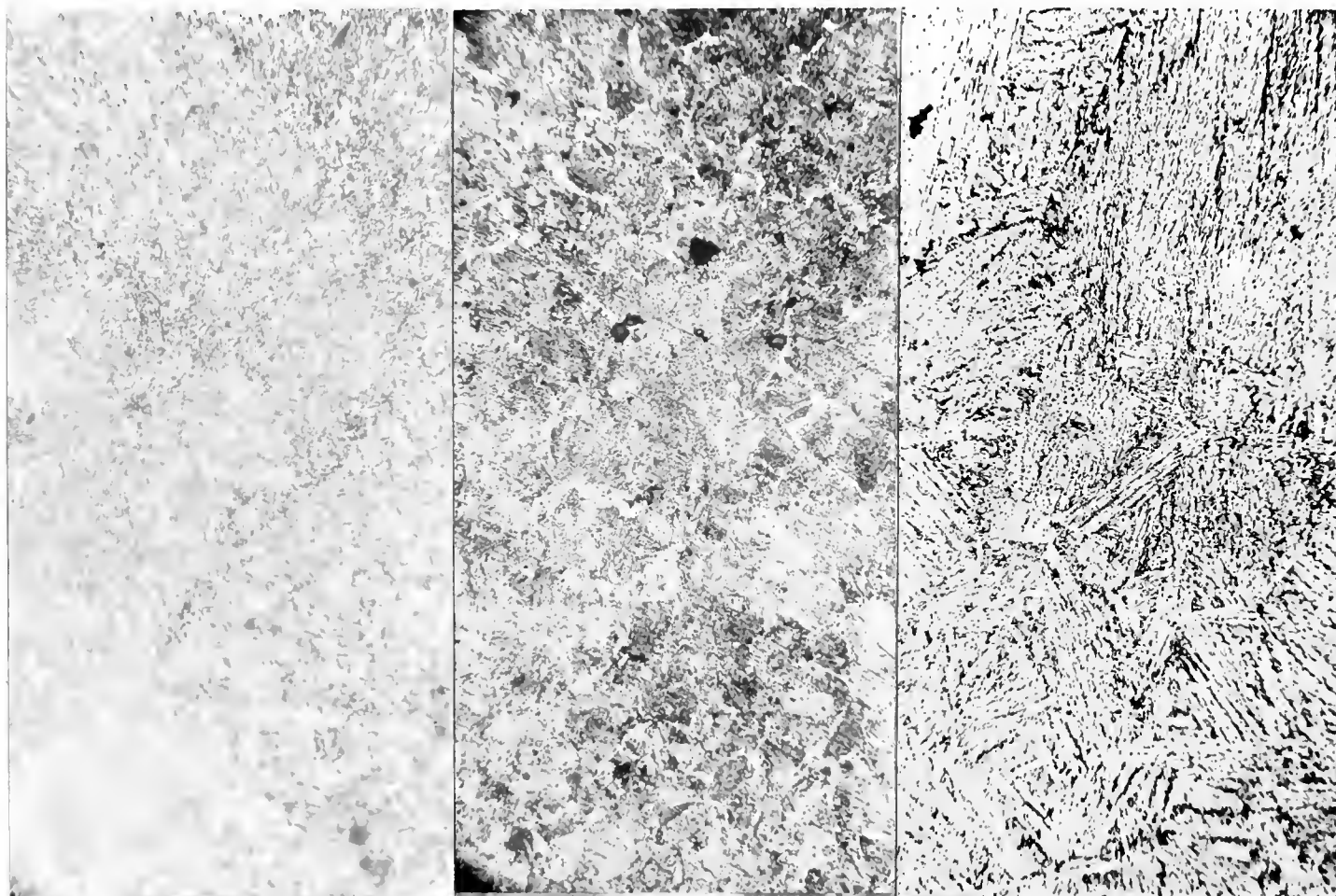
a
At 1600 At 1600

b
At 1850

c
At 2100° F.

Annealed prior to carburizing at temperatures indicated. Carburized at 1615° F. for 12 hours. Steel C.

Figure 2..
Magnification 100X



a	b	c
Annealed from 1600	Annealed from 1850	Annealed from 2100° F.
Steel D		

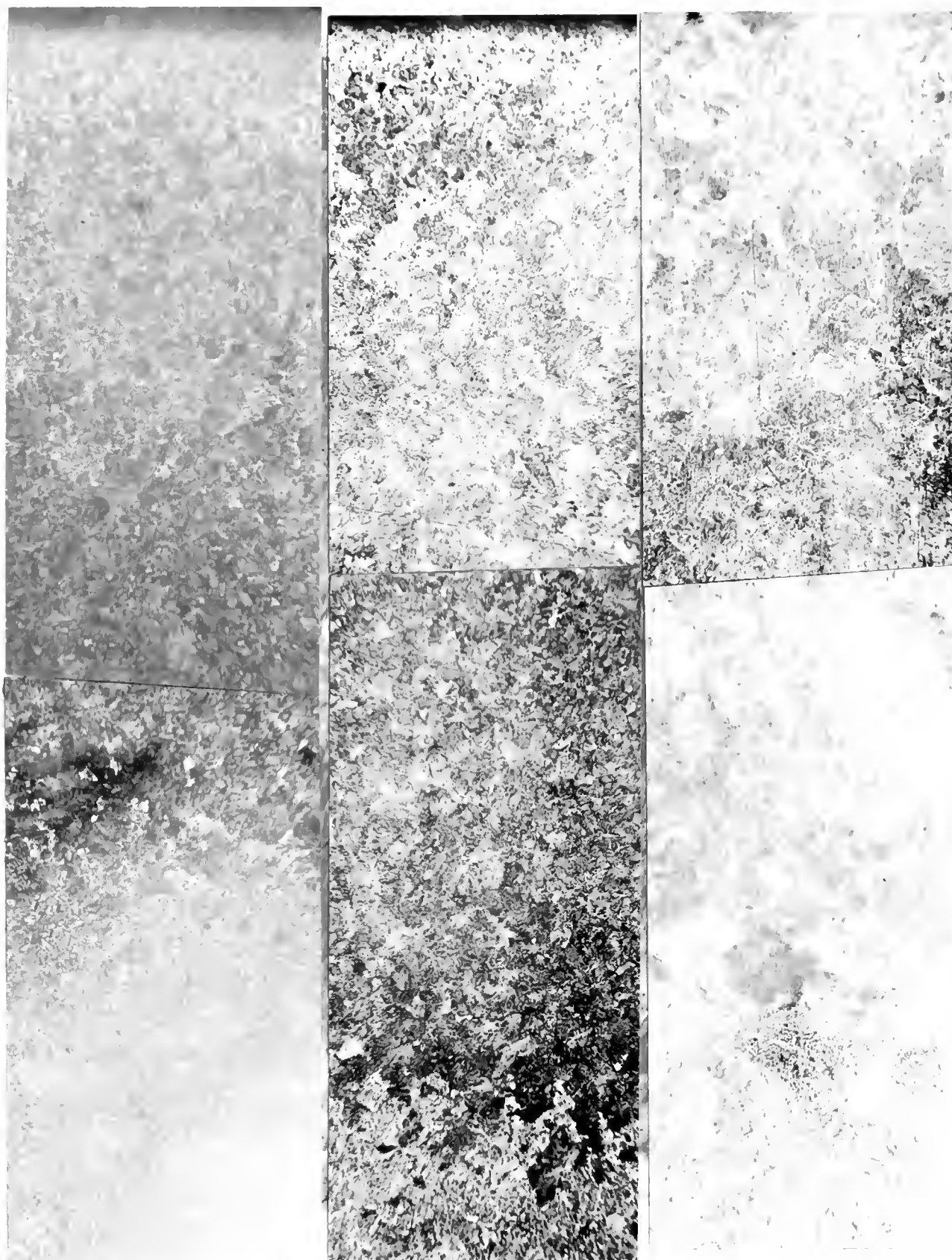
Figure 3. .

Magnification 100 X



Steel D
 Annealed from 1600 °C
 Annealed from 1850 °C
 Annealed from 2100 °C
 Figure 3.

Magnification 100 X



a b c
 Annealed from 1600 Annealed from 1850 Annealed from 2100° F.
 Heat treatment prior to carburizing as indicated. Carburized at 1615° F.
 Steel D.

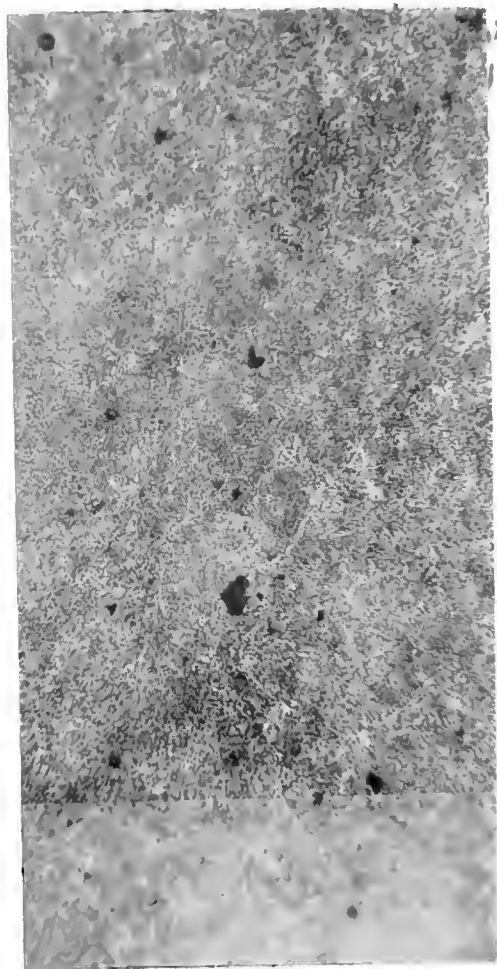
Figure 4..

Magnification 100 X



Steel D.
Heat treatment prior to carburizing as indicated. Carburized at 1610° F.
Annealed from 1600° F. Annealed from 1600° F.
Figure 4..

Magnification 100 X



C 4



D 4

Figure 5..

Magnification 100 X



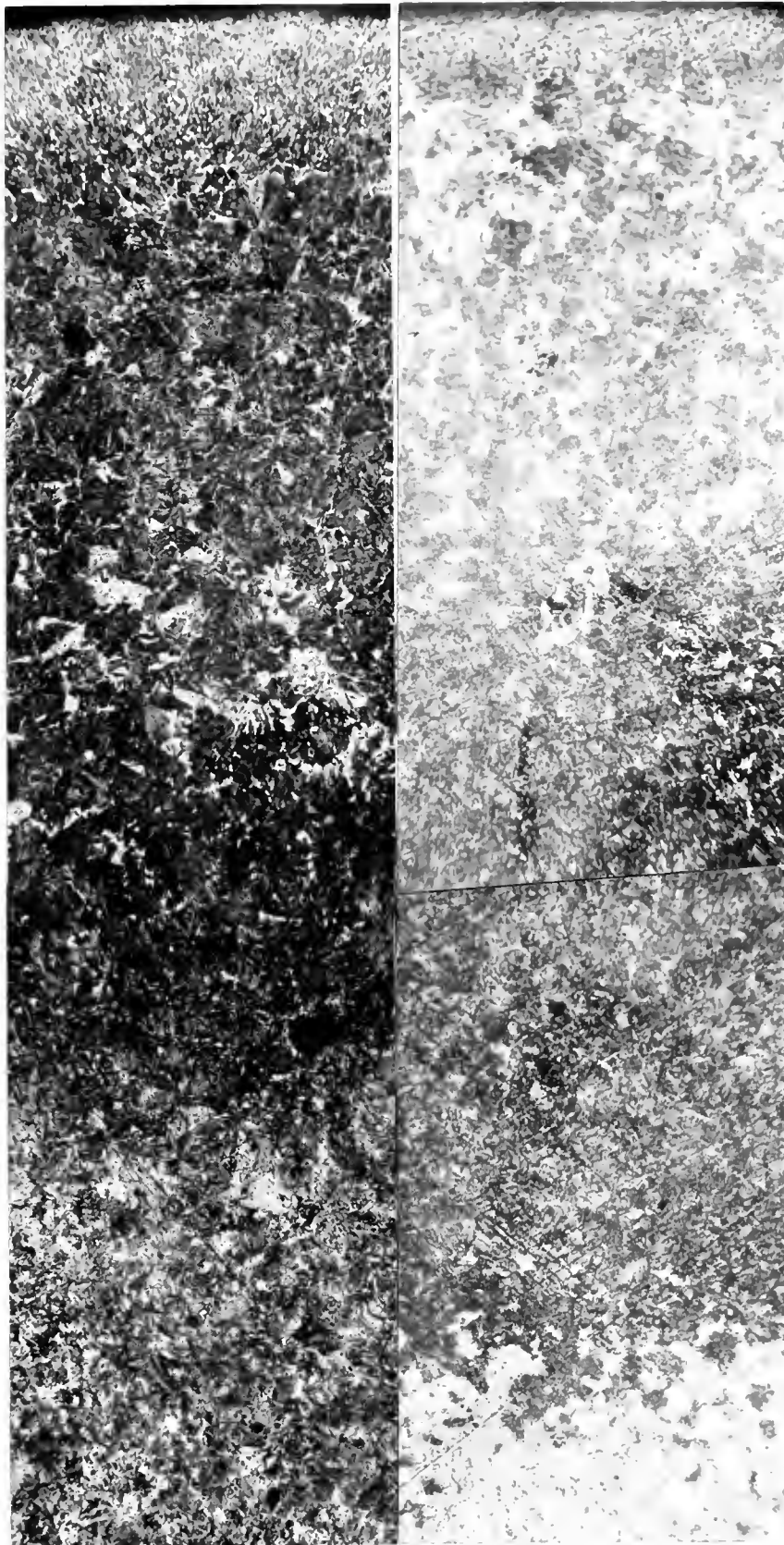
A



B

Figure 2.

Magnification 100 X



a

b

Steel C

Steel D

Annealed prior to carburizing at 1300 F. for 1615 hrs
 1615 for 12 hrs

Figure
 Magnification 100X



6

6

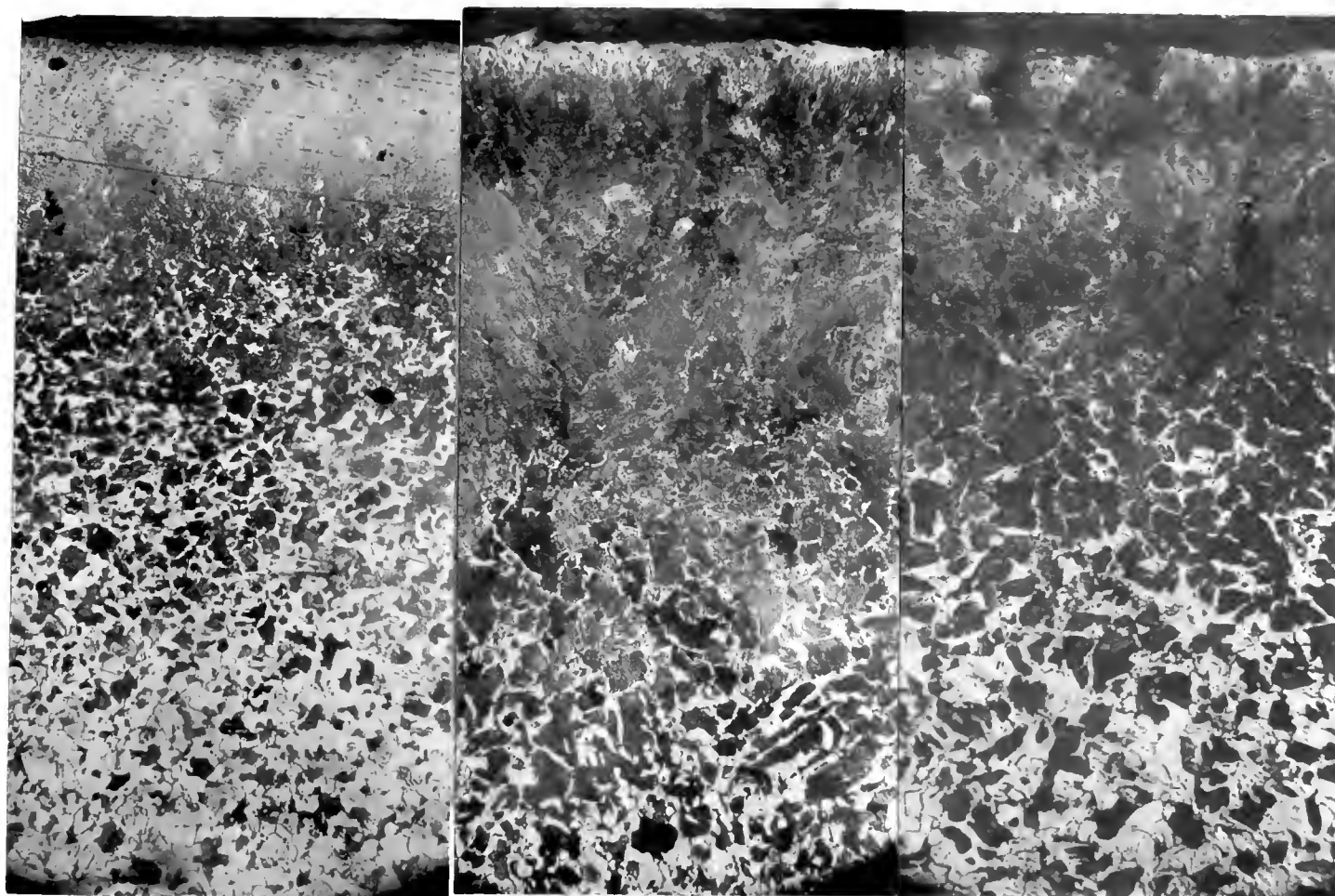
Q. 10000

Q. 10000

APPROXIMATELY 10000 TO 100000 YEARS OLD. THE AGE OF THE FOSILS IS NOT KNOWN.

END

XXXXX



a
Annealed from 1800 F

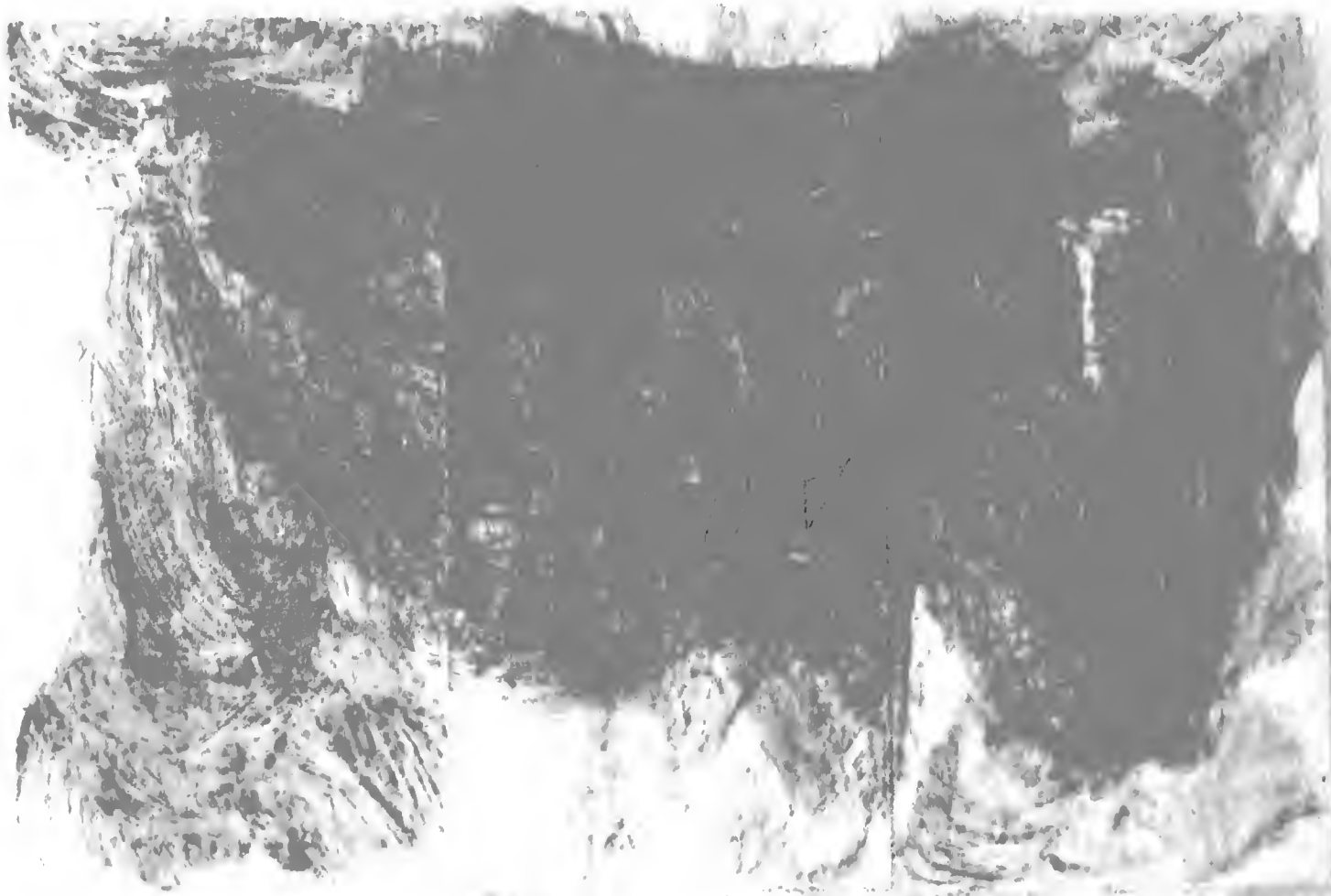
b
Annealed from 2100 F

c
Annealed from 2100 F
Heavily decarburized in
heat treating.

Treatment prior to carburizing as indicated. Carburized at 1635 F for 12 hours. Steel A.

Figure 7.

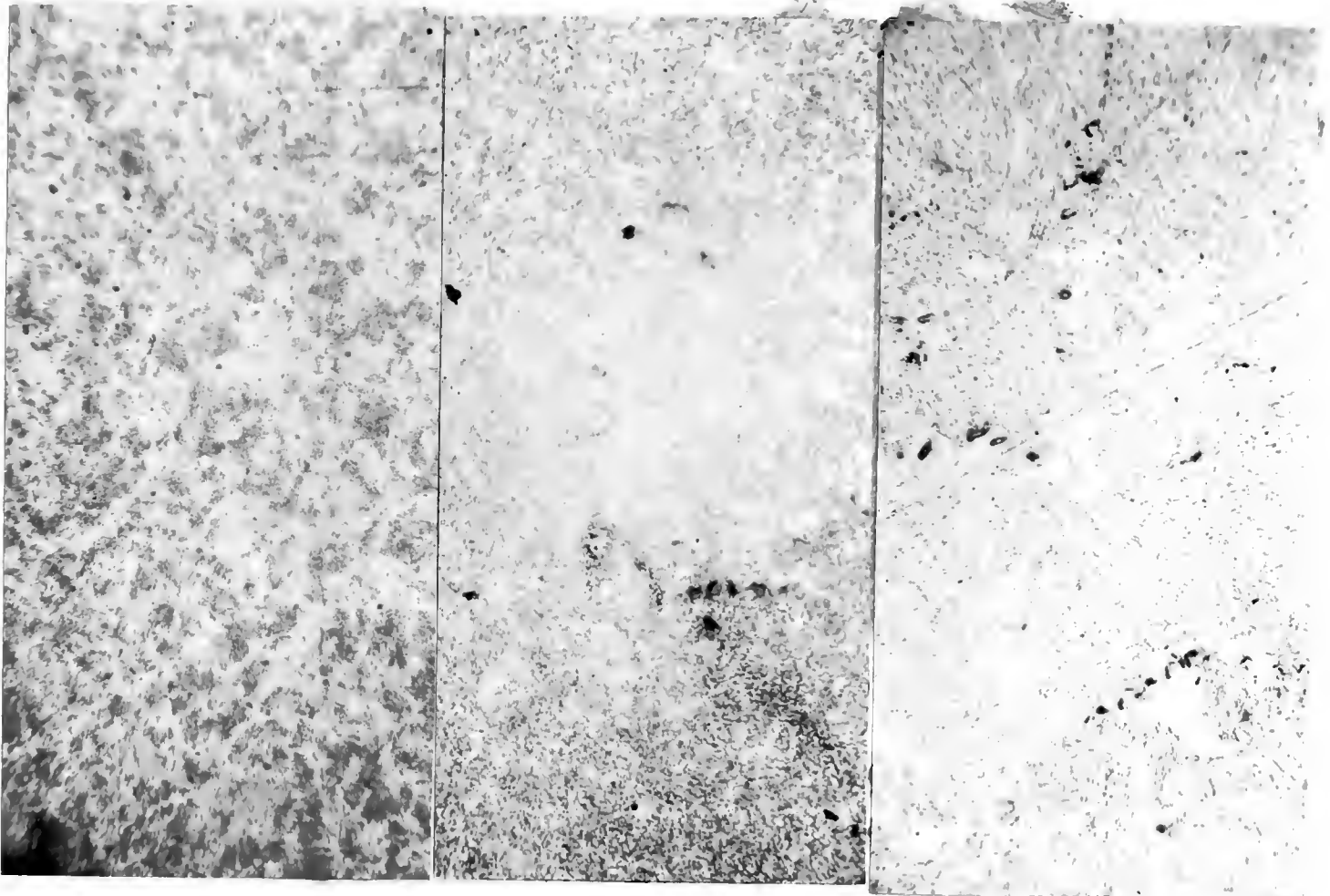
Magnification 100 X



a. Annealed from 1800 F.
 b. Annealed from 2100 F.
 c. Annealed from 2100 F.

Treatment prior to carburizing as indicated. Carburized at 1650 F for
 12 hours. Steel A.

Figure 7.



a
B 1

(Poo)

b
B 2

(B4 or 6)

c
B 3

B 12

Figure 8

Magnification 100 X



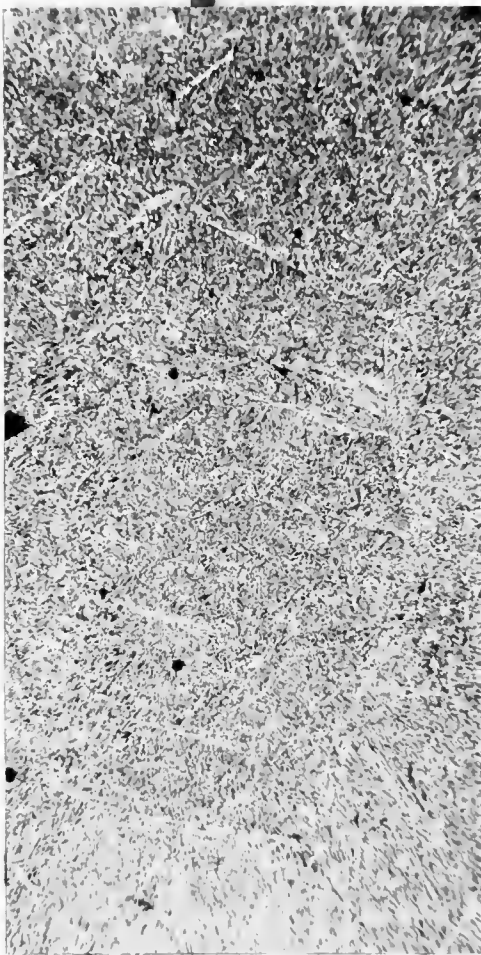
3
B I
(Boo)

p
B S
(B4 or 6)

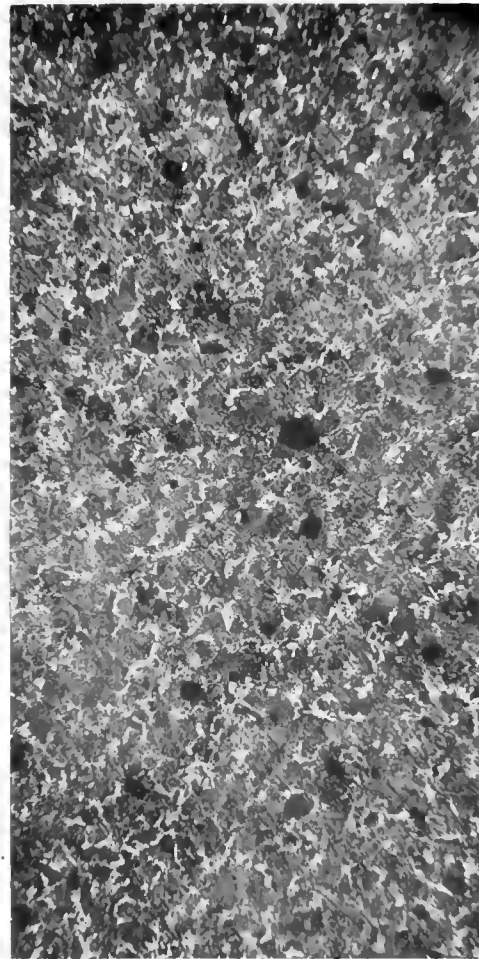
c
B 3
B IS

There 8

Classification 100 X



a
B4
(B7)



b
E1

Figure 9

Magnification 100 X

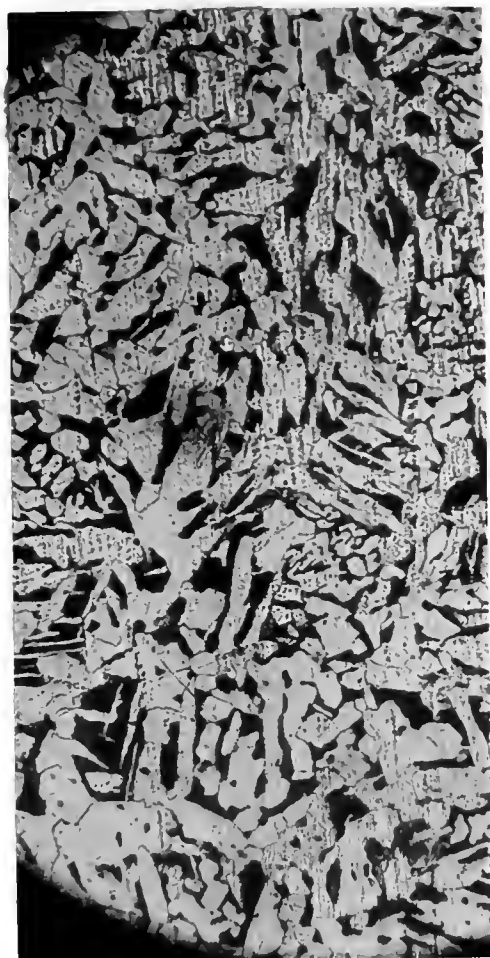


10
 11

12
 13
 14

Figure 2

100 X magnification



Steel A
Annealed at 2100° F.
Figure 10



Figure 10
Annelid at 21000 X.
Steel A

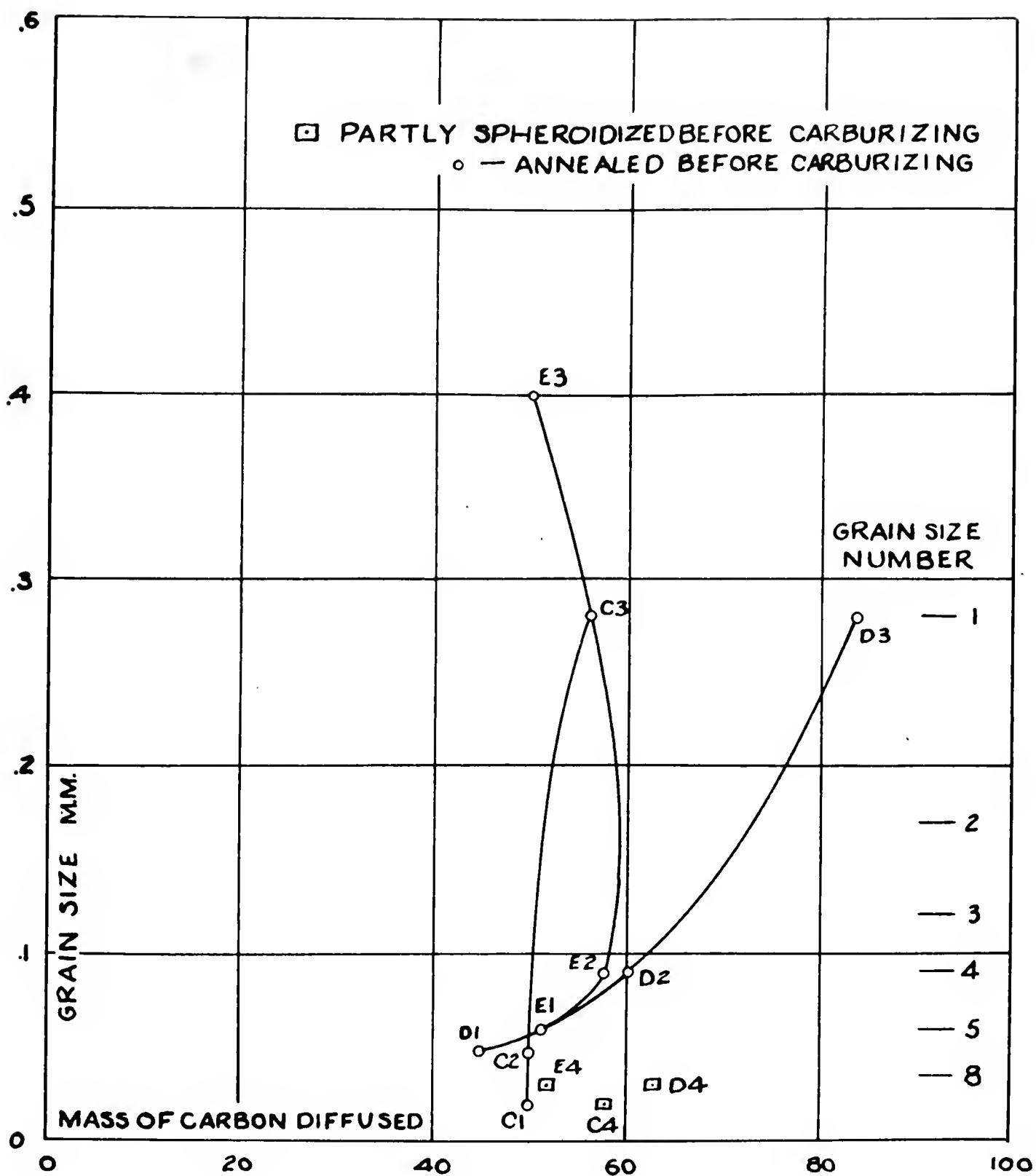


FIGURE 11

COMPARISON OF MASS OF CARBON
DIFFUSED FOR VARIOUS SAMPLES
STEEL C, D, AND G

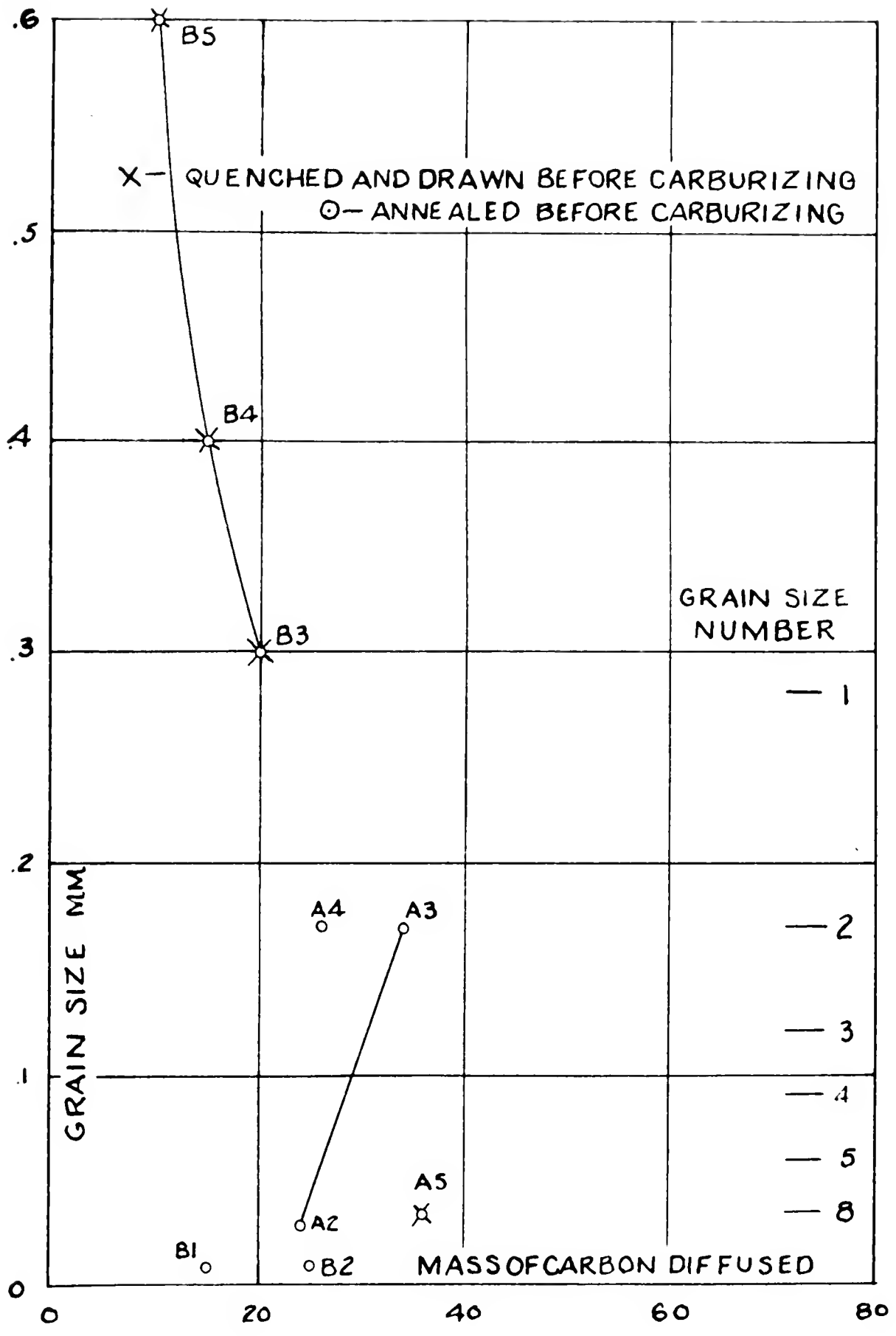


FIGURE 12

COMPARISON OF MASS OF CARBON
DIFFUSED FOR VARIOUS SAMPLES
STEEL A AND B

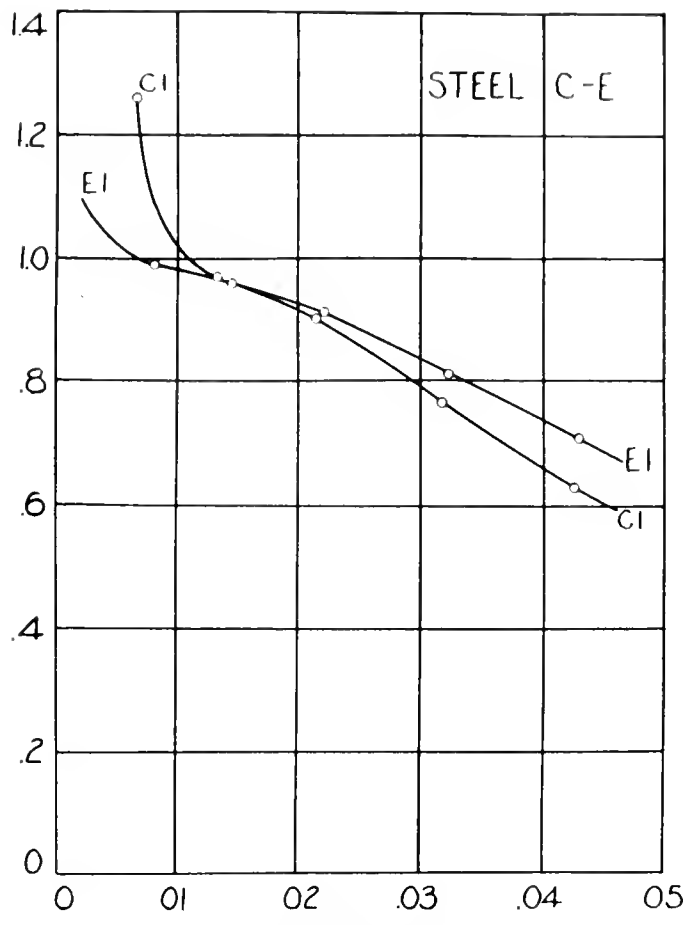


FIGURE 13

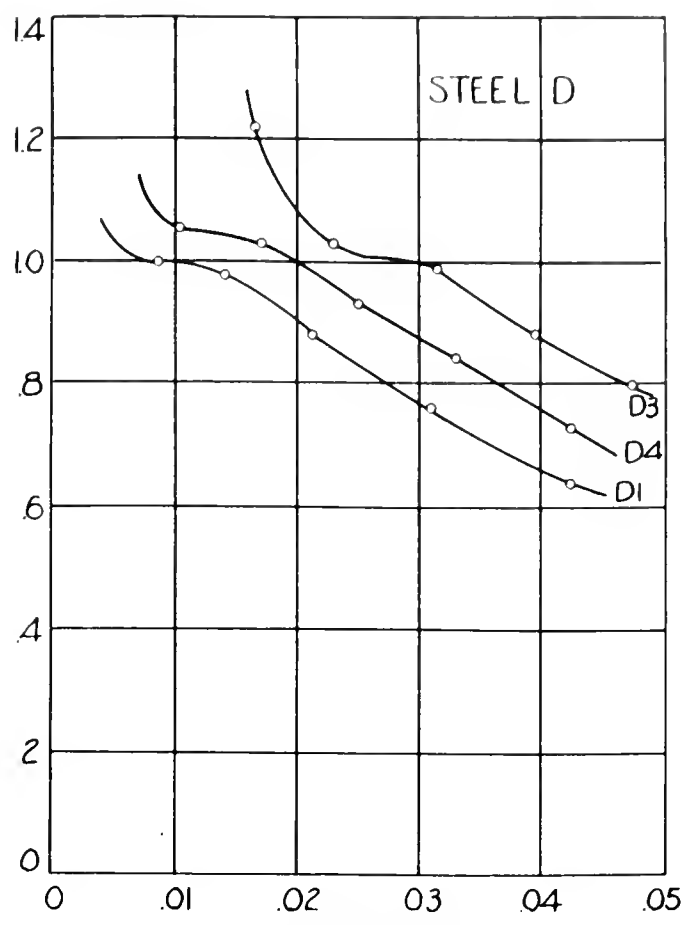


FIGURE 14

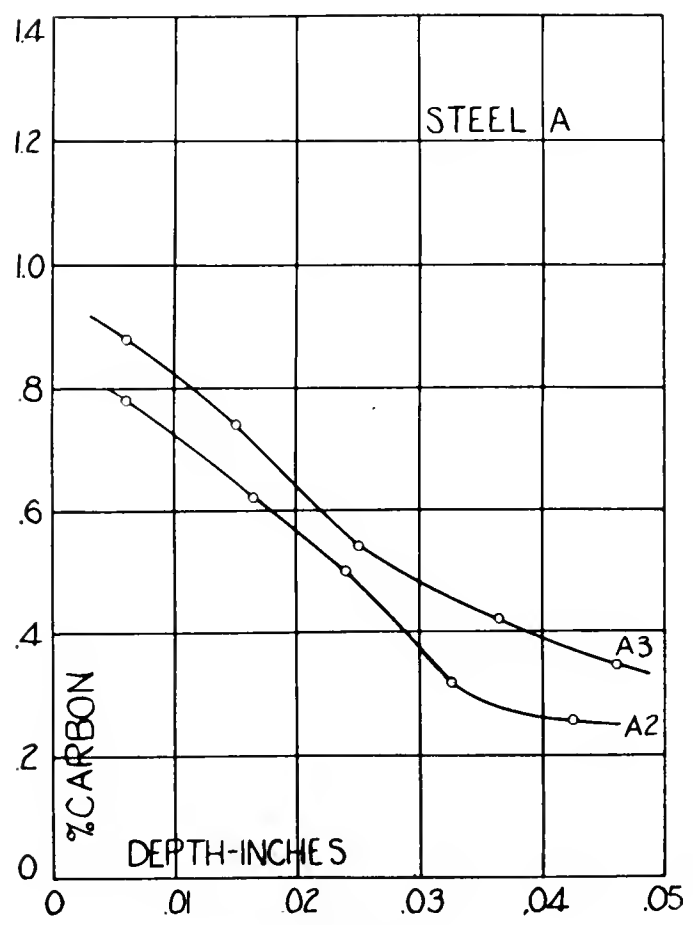


FIGURE 15

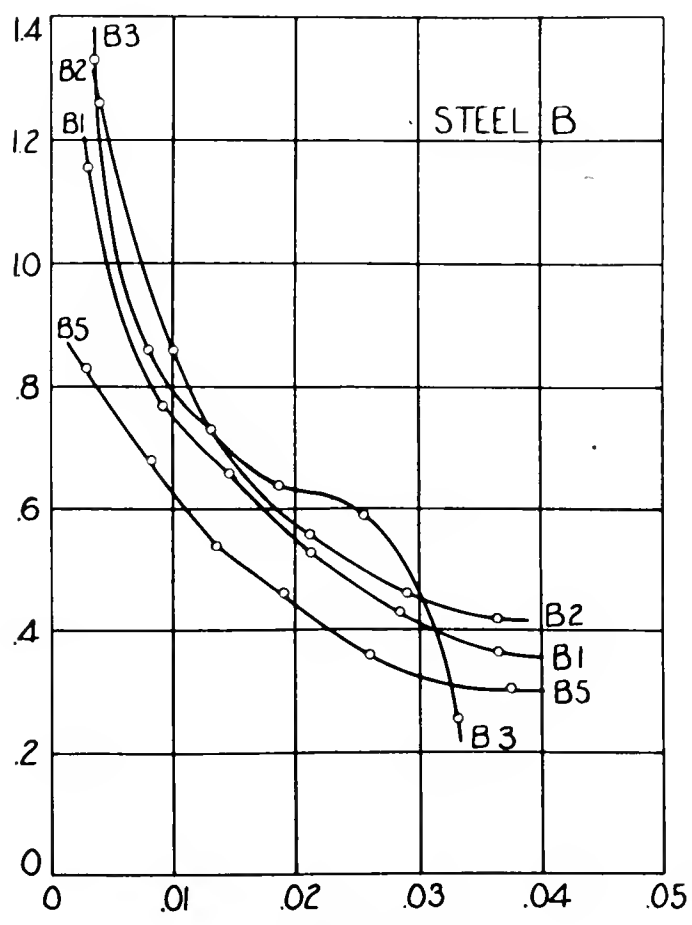


FIGURE 16

CARBON PENETRATION CURVES
CARBON CONCENTRATION PLOTTED AGAINST DEPTH

Table I.

Compositions of steels under test.						
Sample no.	SAE no.	Carbon %	Manganese %	Nickel %	Chromium %	Molybdenum %
A	1020	0.24	0.56		-	-
B	3335	0.34	0.33	3.79	1.72	-
C	3335	0.355	0.48	3.41	1.45	-
D	4335	0.37	0.73	1.75	0.73	0.37
E	3435	0.415	0.47	2.95	0.76	-

Table II.

Histories of individual samples.					Relative mass of carbon diffused during carb.	
Sample no.	Heat to of	Preliminary treatment	Heat to for hours	Manner of cooling	Grain size before carburizing mm.	No.
A1	1800		3	box cooled	0.02	8
A2	1800		3	" "	0.03	7
A3	2100		3	" "	0.17	2
A4	2100		20	" " (oxidized)	0.17	2
A5	1800		2	water quenched	-	-
A6	2100		2	" "	-	-
						24. (estimated from appearance)
						24.2
						34.4
						27.2
						36.6
						35 (estimated by appearance)
B1	as received, drawn at 1200 $\frac{1}{2}$ hr.					
B2	1630		2	cooled in sand	0.01	8
B3	2450		10 and		0.01	8
B4	2150		1	box cooled	0.3	1
B5	2450		10 and			
B6	1850		2	box cooled	0.4	1
	2500		1	box cooled	0.6	1
	2100		1	air cooled	0.2	2
						15.4
						24.2
						19.7
						15.0
						9.8
						9.1 (blued spot after carb.)
C1	1600		2	furnace cooled	0.02	8
C2	1850		2	" "	0.05	6
C3	2100		2	" "	0.28	1
C4	1300		22	" "	0.02	8
						49.7
						49.8
						55.4
						57.2
D1	1600		2	" "	0.05	6
D2	1850		2	" "	0.09	4
D3	2100		2	" "	0.28	1
D4	1300		22	" "	0.03	7
						44.8
						60.3
						84.0
						62.7
E1	1600		2	" "	0.06	5
E2	1850		2	" "	0.09	4
E3	2100		2	" "	0.4	1
E4	1300		22	" "	0.03	7
						52.0
						57.9
						49.5 (blued spot after carb.)
						51.3

.II elder

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.dlas galitub				.on slynes			
(constragge nott bafelile)							
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8.48	8		50.0	yallooc			SA
8.48	8		50.0	beloooc xod			SA
8.48	8		51.0	"			AA
8.48	8		51.0	"			AA
8.48	8		51.0	(beriliko)			AA
8.48	8			bedonouup tefew			AA
8.48	8			"			AA
8.48	8			"			AA

RE	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0	8	4.21	1	9.21	10.0
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Table III.

Data on steels under test			Carbon percentage of Eutectoid %	Carburizing Temp. of	Time hrs.	Difference between Ac3 and carb. temperature	Effect of initial grain size
Steel no.	Critical Ac3	points Ac1					
A	1575	1337	0.82	1635	12	60	yes
B	1350	1345	0.47	1465	"	115	yes
C	1360	1345	0.50	1615	"	265	none
D	1450	1360	0.61	1615	"	165	yes
E	1360	1320	0.60	1615	"	255	none

Table IV

Averaged results of carburizing tests.			Remarks.
Samples	Relative mass of carbon diffused #		
A	(all)	30.6	Similar composition Steels C,D,E - carburized at one time
B	"	16.8	
C	"	53.0	
D	"	63.0	
E	"	52.7	
C1 D1 E1		53.9	Similar treatment
C2 D2 E2		61.6	
C3 D3 E3		73.2	
C4 D4 E4		61.7	

To convert relative mass of carbon to absolute mass in pound per square inch of exposed surface, multiply by 5.9x.513

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